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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Internal Note No. 69-FM-70

MSC INTERNAL NOTE NO. 69-FM-70

March 21, 1969

DEORBIT AND ENTRY CREW TRAINING SIMULATIONS FOR NEAR-EARTH ORBITAL MISSIONS

MISSION PLANNING AND ANALYSIS DIVISION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

(NASA-TM-X-69827) DEORBIT AND ENTRY CREW TRAINING SIMULATIONS FOR NEAR-EARTH ORBITAL MISSIONS (NASA) 37 p

N74-70873

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PROJECT APOLLO

DEORBIT AND ENTRY CREW TRAINING SIMULATIONS FOR NEAR-EARTH ORBITAL MISSIONS

By
Atmospheric Flight Mechanics Section
TRW Systems Group

March 21, 1969

MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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DEORBIT AND ENTRY CREW TRAINING SIMULATIONS FOR

NEAR-EARTH ORBITAL MISSIONS

By W. E. Lee

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TRW Systems Group

1. SUMMARY AND INTRODUCTION

The purpose of this internal note is to supply simulator personnel and flight crews with a specific list of deorbit and entry simulations that should be included during preflight crew training sessions. This document, in general, will be applicable to all earth orbital missions, and it is hoped that it will provide the training that ground personnel and flight crews need in order to have a better understanding of the earth orbital entry problems.

This document is divided into five sections. Following this introductory section, Section 2 provides a list of symbols. Section 3 presents a brief review of the entry trajectory trends for background information; final phase guidance display and keyboard (DSKY) displays are discussed. Section 4 describes the recommended backup entry techniques: entry monitor system (EMS) procedures and bank angle time-to reverse bank angle entries. Section 5 presents the suggested deorbit and entry simulations that are selected to give maximum crew information. The objectives, pertinent monitoring, and trajectory trends are explained for each case.

2. SYMBOLS

AZ	inertial azimuth at entry interface
BBA	backup bank angle
CM	command module
CMC	command module computer
d	deceleration
DAP	digital autopilot
DSKY	display and keyboard
DRE	downrange error (PREDANGLE-THETA)
EMS	entry monitor system
G or g	acceleration of gravity (32.17 ft/sec/sec)
G&N	guidance and navigation
GNCS	guidance navigation and control system
h	local vertical altitude at entry interface
$\dot{H}$	local vertical altitude rate
IMU	inertial measurement unit
LAD PAD	update value for minimum vehicle lift-to-drag ratio
LATANG	crossrange error
LF	load factor
LOD PAD	update value for final phase reference lift-to-drag ratio
L/D	lift-to-drag ratio
$(L/D)_D$	desired lift-to-drag ratio
n mi	nautical mile
P	program
PREDANGLE	final phase ranging potential
R	inertial range
RCS	reaction control system

RDOT	altitude rate
RET	retro elapsed time
RETRB	postburn time to reverse bank angle
$RTOGO_{(V)}$	final phase reference range to go to target
SCS	stabilization and control system
SM	service module
SM/RCS	service module reaction control system
SPS	service propulsion system
THETA	CMC computed range to target
V	inertial velocity
V_{EI}	inertial velocity at entry interface (400, 000 feet altitude)
$\Delta\Delta V_X$	X control system velocity error
$\Delta\Delta V_Z$	Z control system velocity error
γ_{EI}	inertial flight-path angle at entry interface (400, 000 feet altitude)

3. ENTRY TRAJECTORY TRENDS

Discussed within this section are the guidance DSKY displays during final phase (Program 67). The initial display values, as well as display histories as a function of time and target location within the footprint, are discussed.

The function of Program 67 (P67) is to steer the spacecraft to a stored reference trajectory. It does this by using deviations in altitude rate (HDOT), velocity (V), and deceleration (d) combined with stored partials, to compute the desired lift-to-drag (L/D) ratio.

The desired L/D ratio determines the bank angle required to null the terminal range error. The desired lift-to-drag ratio $(L/D)_D$, is computed as follows:

$$(L/D)_D = \text{LOD PAD} + \frac{4(\text{THETA} - \text{PREDANGLE})}{\partial R / \partial (L/D)}$$

where:

LOD PAD = updated value for final phase reference lift-to-drag ratio

THETA = CMC computed range to target (nautical miles)

PREDANGLE = final phase range potential (nautical miles)

The final phase range potential is computed using differences in altitude rate, deceleration, and partials obtained from a stored reference trajectory, which is a function of velocity. The equation is as follows:

$$\text{PREDANGLE} = \text{RTOGO}_{(V)} + \left(\frac{\partial R}{\partial \dot{H}}\right)_{(V)} \Delta\dot{H} + \left(\frac{\partial R}{\partial d}\right)_{(V)} \Delta d$$

where:

$\text{RTOGO}_{(V)}$ = final phase reference range to go to target.

Before the desired L/D ratio is used to generate a bank angle command, g-limiter logic (which monitors current load factor (LF) and assumes control if necessary to prevent excessive loads) and lateral logic (which monitors the currently predicted lateral range error (LATANG) and commands a bank angle direction change when LATANG exceeds a computed deadband) are entered. After passing through these last logic blocks of entry guidance, the bank angle command is computed as follows:

$$\text{bank angle command} = \cos^{-1}\left(\frac{(L/D)_D}{\text{LAD PAD}}\right)$$

where:

$(L/D)_D$ = desired L/D ratio

LAD PAD = updated value for minimum vehicle L/D ratio

Following the bank angle command computation, control is transferred to the digital autopilot (DAP) and subsequently to the reaction control system (RCS) which implements the bank angle command and thus steers the CM to the desired target.

3.1 CMC Bank Angle Commands

The first bank angle command of P67 (other than 0, +15, or -15 degrees) is directly correlated to the time that downrange error (DRE) has a value of approximately zero. DRE (PREDANGLE-THETA) appears in the equation for calculating the desired L/D ratio, and the exact value which causes the first bank angle command in P67 is a function of LAD PAD and LOD PAD. Presented as a function of target contour position in Figure 1 is the magnitude of the first bank angle command computed by the P67 logic. The first command will be 0, +15, or -15 degrees unless the target is located between the 78- and 90-degree contours; in which case, the first commands will be as shown in Figure 1.

Figures 2 through 7 present typical command module computer (CMC) displays of commanded bank angle, crossrange error, and downrange error as a function of elapsed time from 400,000 feet altitude. It should be noted that the parameters are not displayed until entry into Program 67, which occurs at 0.2g. The sign of the initial bank angle commands is dependent on LATANG and could be of opposite sign than those shown in Figures 2 through 7. The purpose of presenting these guidance parameters is to show the variation in each parameter as a function of time caused by the location of the target within the open-loop footprint. A typical open-loop footprint and target locations are presented in Figure 8.

3.2 Crossrange Error Display

Crossrange error (LATANG) is displayed in DSKY register 2 during Program 67. Crossrange error is computed in the targeting phase and is used in lateral logic to determine the sign of the bank angle command. For properly operating lateral control logic, crossrange error magnitudes of up to 45 nautical miles (depending upon target contour location) are permitted during the first 3 minutes of final phase guidance. For center line targets, a small initial error will reach values of approximately 30 nautical miles before the bank angle is reversed. Figure 9 presents the crossrange deadband as a function of inertial velocity for a nominal end of mission entry. It can be seen that the deadband decreases rapidly as a function of velocity which causes the crossrange errors to converge, thereby steering the CM to the target in crossrange. Figures 2 through 7 show the DSKY display of crossrange error as a function of time from the entry interface (400, 000 feet altitude) and target location within the footprint. The large initial values of LATANG noted in Figures 4 and 7 result from targets that lie on the edge of the footprint, rather than along the trajectory ground track.

3.3 Downrange Error Display

Downrange error (DRE) is computed during Program 67 and displayed in DSKY register 3. For targets near the toe of the footprint, this parameter increases rapidly towards zero during the first part of P67. The rate of convergence of DRE is dependent on the actual vehicle L/D. During this period, the lift-vector orientation remains at zero degree or lift-up (±15 degrees as a result of lateral logic). It is not until downrange error approaches zero that a bank angle command other than lift-up is required. The duration of time that lift-up is commanded is dependent upon the initial value of downrange error and, consequently, target location within the maneuver footprint. If the target is at the toe of the footprint, the initial downrange error is a large negative value and a lift-up trajectory is required throughout entry to achieve the target. If the target is at the heel of the maneuver footprint, the initial downrange error is a small positive value, and bank angle commands other than lift-up are required immediately to keep from overshooting the target. The relationship between downrange error and target location can be seen in Figure 10. Downrange error and initial bank angle command relationships as a function of target location can also be seen in each of the CMC entry displays versus elapsed time from 400, 000 feet altitude (Figures 2 through 7).

The oscillatory effect observed in the downrange error curves noticeable in Figures 3 through 7 is the result of the interpolation between the data points of the stored reference trajectory. The last "hump," which occurs at approximately 315 seconds (Figures 6 and 7), is the result of the bank angle command generated by g-limiter logic in order to prevent excessive load factors.

4. BACKUP ENTRY TECHNIQUES

The primary entry technique to be used following a nominal CMC controlled, service propulsion system (SPS) deorbit is to manually maneuver the CM to aerodynamic trim with lift vector up, and then, at 0.05 g, give control to the digital autopilot (DAP) which will steer to the bank angle commands generated by the command module computer. At retro elapsed time (RET) 0.2 g, the crew will make a go/no-go check on the guidance and navigation control system (GNCS). If the GNCS is go, the crew will use CMC-DAP control during the entry phase. Following the go/no-go check, the crew will continue to monitor the CMC display and keyboard (DSKY) to verify that the CMC is responding to onboard commands, that the CMC is sequencing through programs and displaying parameters as designed, and that certain display parameters compare, within tolerances, to values computed by ground support facilities or obtained by the crew from onboard charts.

The recommended backup control procedures are dependent upon the position of the command module (CM) within the entry corridor (Figure 11), the time in the return-to-earth sequence that take-over of the guidance and navigation control system (GNCS) becomes necessary, the availability of EMS initialization values, and the status of the CM/RCS systems. A detailed description of the entry monitoring and backup control procedures can be found in Reference 1. Table I presents a summary of the recommended backup control techniques to be used in the event of a GNCS failure for a typical earth orbital mission. Discussed below are the backup entry modes which are presented in Table I.

4.1 EMS Procedures

The primary backup entry technique for earth orbital missions is the EMS ranging technique. It has been recommended over other entry techniques for several reasons, all of which are discussed in Reference 2. The primary reason, however, is its accurate ranging capabilities. The estimated accuracy of the EMS for earth orbital missions is ±34 nautical miles (3σ) and is documented in Reference 2.

4.1.1 EMS initialization procedures. - Under nominal conditions there are three sources of EMS initialization values available to the crew: (1) preburn values, (2) postburn values, and (3) CMC computed values which will be displayed during Program 61. The EMS should be initialized using the more accurate postburn initialization values and started manually at RET 0.05 g. In the event the postburn EMS initialization values are not available due to voice communication failures, the EMS should be initialized using preburn initialization values and started manually on time using the preburn value of RET 0.05 g. The EMS initialization values computed by the CMC and displayed on DSKY during Program 61 are not recommended for use since the EMS quantities are computed using the preburn state vector and therefore may not include the correct burn maneuver if problems in the CMC or IMU have occurred.

4.1.2 EMS ranging technique. - As previously stated, the backup entry techniques are dependent on the position of the CM within the entry corridor. For a nominal entry position within the corridor, between the mode 1 or lift vector up overshoot boundary and the 10-g undershoot boundary (Figure 11), the initial entry attitude into the atmosphere is to maintain the lift vector up until RET 0.2 g, at which time the CM is oriented to the backup bank angle attitude. The backup bank angle must be maintained until the EMS display can be interpreted (approximately 1 g). For shallow entry positions within the corridor, above the lift vector up overshoot boundary, the initial entry attitude into the atmosphere is to maintain lift vector down until 1 g. After the EMS display can be interpreted, regardless of the initial entry attitude discussed above, EMS ranging can begin.

As soon as the EMS scroll can be interpreted, the crew should begin to modulate the lift vector to conserve ranging potential during the first or early phase of the entry. It is necessary to initially maintain a ranging potential in excess of the range to go in the EMS range counter. Conservation of the ranging potential is required to guard against L/D and atmospheric dispersions.

At the postburn time to reverse the bank angle (RETRB), the CM lift vector attitude must be oriented to the reverse backup bank angle to minimize the crossrange error. After reversing the lift vector orientation, the crew should modulate the lift vector as required to cause the difference between the EMS range counter and the range potential lines of the EMS scroll to be nulled. It is recommended that the difference be nulled when the range to the target is between 300 and 200 nautical miles.

Following the initial nulling of the difference between the range counter and the range potential lines, the counter and potential lines must be continuously monitored. Minor adjustment in the lift vector orientation will be required to maintain the null.

The null between the counter and the range potential lines should be maintained as long as possible even though the scroll pattern terminates at an EMS velocity of 4,000 feet per second. It is recommended that the range counter be flown to zero at 25,000 feet altitude. This can be accomplished by monitoring the EMS range-to-go counter, rate of change of the counter, and the altimeter.

The procedures discussed above are the recommended EMS ranging procedures which are designed to take advantage of the capabilities of the EMS and, therefore, minimize the target miss distance. Figure 12 shows typical EMS velocity-G traces for G&N controlled entries to centerline targets. A table relating the maneuver capability for the 55-degree centerline target to the V-G trace is also included in Figure 12.

4.2 Bank Angle/Time-To-Reverse Bank Angle Entry

The bank angle/time-to-reverse bank angle entry technique is recommended in the event the EMS is not operational or fails during entry. Using this technique for nominal positions within the entry corridor, the crew should maintain aerodynamic trim with lift vector up until RET 0.2g, at which time the crew should orient the lift vector north (bank angle is positive) to the backup bank angle (BBA). At a predetermined retro elapse time to reverse bank angle (RETRB), the crew should orient the lift vector south to the reverse BBA (bank angle is negative).

The crew has two sources from which to get the BBA and RETRB; the postburn entry update and the backup charts. If the postburn update is available, the entry should be made using this data source. If the postburn update was not received because of communications failure, the BBA and RETRB must be obtained from the entry backup chart. This chart is based on the deorbit delta-velocity errors in the X- and Z-control system axis ($\Delta\Delta V_X$ and $\Delta\Delta V_Z$, respectively). If an off-nominal SPS deorbit burn occurs, BBA and RETRB must be updated based on the magnitudes of $\Delta\Delta V_X$ and $\Delta\Delta V_Z$ displayed to the flight crew on DSKY during P40. Figure 13 is an example of the onboard entry backup chart which will be used to obtain BBA and RETRB. Downrange error (DRE) which is used to make the CMC go/no-go decision for entries without voice communications is also included on this chart.

4.3 Ballistic Entry

For CM-RCS propellant critical situations (with only one RCS system operative, containing 40 pounds of propellant or less) the recommended entry technique is a rolling ballistic entry. This entry technique is recommended to conserve RCS propellant and insure a safe entry. For nominal positions within the entry corridor, the procedure is to maintain aerodynamic trim with lift vector up until 0.2g and then initiate a 20-degree/second roll rate about the CM stability axis. After the roll rate is established, the RCS rate damping is disabled until after maximum deceleration. After maximum g, the RCS rate damping is initiated and the roll rate stopped. A 90-degree attitude hold in roll is maintained until drogue chute deployment. The recommended procedure for shallow positions within the corridor is to maintain aerodynamic trim with lift vector down until 1.0 g, initiate the 20-degree/second roll rate, and follow the same procedure as outlined above for nominal positions within the entry corridor.

5. DEORBIT AND ENTRY SIMULATIONS

This section presents the suggested deorbit and entry simulations that have been selected to give the maximum crew information. The objectives of each simulation and pertinent entry monitoring and trajectory trends are explained for each case. Table II contains a summary list of the suggested simulations listed in the order of their priorities.

5.1 Deorbit and Entry Timeline Checkout Simulations

The first six runs in Table II should be combined deorbit and entry timeline checkouts. These simulations will evaluate and verify ground/crew procedures including data flow and timelines. Although it is true that both the deorbit and entry maneuvers can be analyzed separately, the crew training and timeline evaluation on such an important aspect of the nominal mission should be completed early in the simulation program so that ground/crew sequences can be verified as early as possible. References 3 and 4 contain detailed ground and crew activity schedules and procedures to be used during entry and entry training.

Runs 1, 2, and 3 simulate a CMC controlled, SPS deorbit with a manual entry flight mode. A manual entry mode is suggested (crew flies CMC attitude error needles) so that the crew will become familiar with the bank angle command time histories. These first three runs simulate a nominal deorbit which results in a nominal CM position within the entry corridor. Run 1 continues this nominal simulation throughout entry to the nominal 55-degree centerline target. CMC DSKY display time histories will be nominal and have trends similar to those shown in Figure 5. Runs 2 and 3 are repeats of run 1 except for CM L/D variations (± 0.03). These simulations will demonstrate the differences in the bank angle commands for the nominal L/D and the low and high L/D cases. Run 2 (low L/D) will reflect the longer than nominal lift vector up attitude required to reach the target and the delay in the bank angle command reversal produced by a longer time required to reach the crossrange deadband. Run 3 will demonstrate a less than nominal duration for lift vector up attitude, and a bank angle command reversal sooner than nominal since the higher L/D will cause the crossrange deadband to be reached earlier in the flight. Runs 4 and 5 simulate a CMC/SCS controlled, SPS deorbit with a manual entry flight mode. An SPS overburn is simulated in run 4 with a manual entry to a 30-degree centerline target of the new maneuver envelope. The overburn is not of sufficient magnitude to cause the CM to be out of the original maneuver envelope associated with a nominal SPS deorbit, but has shifted the envelope so that the 55-degree centerline target lies on the 30-degree contour of the new maneuver envelope. Run 5 simulates an SPS underburn and a maneuver envelope shift so that the target is now located on the 80-degree contour of the new maneuver envelope. Run 6 completes the SPS deorbit simulations. This run is completely automatic. A CMC controlled nominal SPS deorbit is combined with a CMC controlled entry to the nominal 55-degree centerline target. It is important that the crew compare the DSKY and FDAI for this nominal simulation with those produced by the overburn and underburn simulations. This comparison will give experience in evaluating the data changes for off-nominal conditions.

A word of caution on the CMC operation; the CMC commands may be flown manually or in the auto mode; however, the magnitude and direction of the CMC commands must be used and should not be modified if a successful CMC guided entry is desired.

5.2 EMS Entry Simulations

Second priority should be given runs 7 through 14 which are EMS runs with various targets and L/D variations. These test runs will give the crews adequate experience in evaluating the EMS backup ranging capability and limitations for the various L/D's and targets. For these EMS simulations, a nominal lift vector up attitude should be maintained until 0.2 g. At 0.2 g, the CMC should be oriented to the backup bank angle and the entry completed using the EMS ranging techniques as described in Section 4.1.2. Runs 7, 8, and 9 will be targeted for the 55-degree centerline target with nominal, low, and high lift-to-drag ratios simulated for the spacecraft. The L/D variations will give experience in evaluating the ranging potential of the spacecraft. Runs 10 through 14 are additional EMS entries which will demonstrate the value of experience and the pilot skill that can be developed with the EMS entry technique.

5.3 CMC Failure and EMS Takeover Simulations

Third priority should be placed on runs 15 through 19 which stress EMS takeovers during a CMC controlled entry that presumably fails after the 0.05-g level. For simulations 15, 16, and 17, a nominal entry trim attitude with lift vector up should be maintained until 0.05 g. At 0.05 g, control should be given to DAP and at 0.2 g the final CMC check is made. At 0.2 g, the CMC is failed, the CM is oriented to the backup bank angle, and the entry completed using the EMS technique. These three runs will be targeted to different positions within the footprint requiring initial orientation to different backup bank angles at 0.2 g. Much of the spacecraft maneuver capability is lost in the first few minutes of entry, and it is important that the backup bank angle be reached as soon as possible after the CMC failure at 0.2 g. EMS ranging is used to complete the entry to the assigned targets.

Simulations 18 and 19 should be flown as discussed above except the CMC is failed later in the entry sequence. These runs should be repeated and the CMC failed at various times during entry requiring an EMS takeover at varying ranges from the target.

5.4 Hybrid Deorbit and Entry Simulations

Fourth priority should be on the combined SM-RCS/CM-RCS (hybrid) deorbit and entry maneuvers. Runs 20 through 23 will give experience with the hybrid deorbit maneuver and also CMC and EMS entries after the deorbit maneuver. A SM-RCS/CM-RCS deorbit may put the spacecraft above the lift-up overshoot boundary of the entry corridor. Nominal entry from this position requires a manually controlled entry with lift vector down until 1.0 g. After the initial manual entry to 1.0 g, runs 20, 21, and 22 simulate a CMC DAP controlled entry to 55, 80, and 40 degrees centerline targets of the SM-RCS/CM-RCS maneuver envelope. Run 23 is to be flown in the same manner as the above simulations except at 1.0 g the CMC is failed, and the EMS entry technique is used to reach the 55-degree centerline target of the SM-RCS/CM-RCS footprint. These simulations will evaluate and verify ground/crew procedures and timelines for the hybrid deorbit. They will also evaluate entry steering, EMS ranging, and propellant gauging for this type of deorbit and entry mode.

5.5 Manual and Automatic Controlled Entry Simulations

Fifth priority would be runs 24 through 32. These are manual and automatic controlled entries. These simulations give the crews additional experience with CMC DSKY display trends for various target locations within the nominal maneuver envelope. Runs 24, 25, and 26 are manually controlled entries to off-nominal targets. The objectives are to evaluate crew capability in following the CMC commands and to demonstrate the CMC trends for the different target locations. Figures 3 through 7 are examples of the trends which can be expected for these simulations. Runs 27, 28, and 29 are repeats of the above examples except control will be provided by CMC-DAP, and the crew will monitor the CMC and EMS trends. Figures 3 through 7 are examples of the trends which can be expected. The final runs 30, 31, and 32 will be targeted to the 55-degree centerline target. Again these simulations will be CMC DAP controlled, and the crew will monitor DSKY trends. These runs will demonstrate the CMC trends as a function of vehicle L/D.

5.6 Bank Angle/Reverse Bank Angle Entry Simulations

If the EMS is not operative or fails during an EMS entry, it is recommended that the entry be completed using the bank angle/reverse bank angle entry technique. Since the bank angle/reverse bank angle technique is an integral part of the EMS ranging technique, it may be decided that sufficient bank angle/reverse bank angle experience has been acquired at this point in the crew training. If, however, it is decided that further simulation experience is desired, runs 7 through 14 may be repeated as pure bank angle/reverse bank angle entries. These simulations which include various targets and L/D variations should give adequate experience with this type entry.

Table I. Recommended Backup Entry Techniques for Near-Earth Orbital Missions

Position in Entry Corridor	CM/RCS Status	Backup Entry Technique: GNCS Failure Prior to Final Phase Steering	Backup Entry Technique: GNCS Failure During Final Phase Steering
Between lift vector up overshoot boundary and 10-g zero-lift undershoot boundary	At least one RCS system available and a minimum of 40 pounds of propellant	Maintain aerodynamic trim with lift vector up until 0.2 g, then EMS entry technique.	EMS recommended for this case
Between lift vector up overshoot boundary and 10-g zero-lift undershoot boundary	Only one RCS system available with less than 40 pounds of propellant	Initiate 20 deg/sec roll rate; inhibit all RCS rate damping; after max-g stop rate; 90-deg attitude hold with rate damping until drogue.	N/A
Above lift vector up overshoot boundary	At least one RCS system available and a minimum of 40 pounds of propellant	Maintain aerodynamic trim with lift vector down until 1 g, then EMS entry technique.	EMS recommended for this case
Above lift vector up overshoot boundary	Only one RCS system available with less than 40 pounds of propellant	Initiate 20 deg/sec roll rate; inhibit all RCS rate damping; after max-g stop rate; 90-deg attitude hold with rate damping until drogue.	N/A

Notes: (1) If EMS initialization values are not available, the EMS is not operative, or fails during an EMS entry, it is recommended that the entry be completed using the bank angle/time-to-reverse bank angle entry technique.

(2) In the event of emergency block data deorbit without voice communications, the recommended entry is the 55/55 bank reverse bank entry technique.

Table II. Recommended Run List for Near-Earth Orbital Entry Simulations

Run	Deorbit Flight Mode	Reentry Flight Mode	State Vector	Reentry Interface Lat Long	Reentry Target	L/D	Weight	Pilot Task	Flight Mode	Objectives
1						Nominal				
2	Auto CMC		Nominal	Nominal	55 center	Low				
3		Manual				High		Verify existing ground/crew procedures and data flow	Crew flies CMC attitude error needles	Evaluate ground/crew procedures data flow and timelines
4	SPS		Overburn	Overburn	30 center*		Nominal			
5	SCS Auto		Underburn	Underburn	80 center**	Nominal				
6	Auto CMC	CMC	Nominal	Nominal	55 center				CMC Auto	
Reentries Only										
7		SCS				Nominal				
8		SCS			55 center	Low				
9	N/A	SCS	Nominal	Nominal		High	Nominal	Use the bank angle and time to reverse bank angle technique initially and trim the reentry maneuver using the EMS		
10		SCS			90 center	Nominal				To evaluate the backup reentry technique for earth orbit missions
11		SCS			80 center	High			Rate CMD ACC CMD	
12		SCS			70 off center	Nominal				
13		SCS			30 off center	Low				
14		SCS			40 center	Nominal				
15		CMC/SCS			55 center					
16		CMC/SCS			30 off center			CMC failure after 0.05 g Fly EMS		To evaluate EMS takeover after CMC failure conditions during reentry
17	N/A	CMC/SCS	Nominal	Nominal	70 off center	Nominal	Nominal		Rate CMD	
18		CMC/SCS			55 center			CMC fails at various times during reentry and EMS takeover is required		
19		CMC/SCS			70 off center					

*30-degree centerline target of new maneuver envelope, 55-degree centerline of nominal maneuver envelope

**80-degree centerline target of new maneuver envelope, 55-degree centerline of nominal maneuver envelope

Table II. Recommended Run List for Near-Earth Orbital Entry Simulations (Continued)

Run	Deorbit Flight Mode	Reentry Flight Mode	State Vector	Reentry Interface Lat / Long	Reentry Target	L/D	Weight	Pilot Task	Control Mode During Reentry	Objectives
20					55 center					
21	SM-RCS/CM-RCS hybrid deorbit mode		SM-RCS/ CM-RCS	On RCS target line	80 center			Manually fly lift vector down to 1 g then use CMC DAP	ACC CMD until 1 g then CMC DAP	To evaluate deorbit maneuver and reentry steering and propellant gauging throughout this type of deorbit and reentry mode
22		CMC			40 center	Nominal	Nominal			
					55 center					
23		SCS			55 center			Manually flylift vector down to 1 g then use EMS	Rate CMD ACC CMD	To evaluate EMS ranging for this type of reentry mode
Reentries Only										
24					90 center			Observe CMC commands and trends for different target locations	Crew flies CMC attitude error needles	Evaluate crew capability in following CMC commands and observing CMC trends for different target locations
25		Manual			30 off center					
26					70 off center					
27					90 center			Monitor CMC, EMS, and SCS trends	Monitor	Monitor CMC and observe CMC trends for different target locations
28	N/A		Nominal	Nominal	30 off center	Nominal	Nominal			
29		Auto			70 off center					
30					55 center	Nominal				Fuel consumption, DAP control versus manual, and touchdown dispersion data
31						High				
32						Low				

Notes: (1) For guidance runs LAD and LOD in erasable memory should be 0.25 and 0.225, respectively.
(2) Auto: CMC controlled
(3) Manual: Astronaut closes loop using CMC commands
(4) SCS Astronaut flies backup mode (i.e., constant bank, rolling, or EMS)

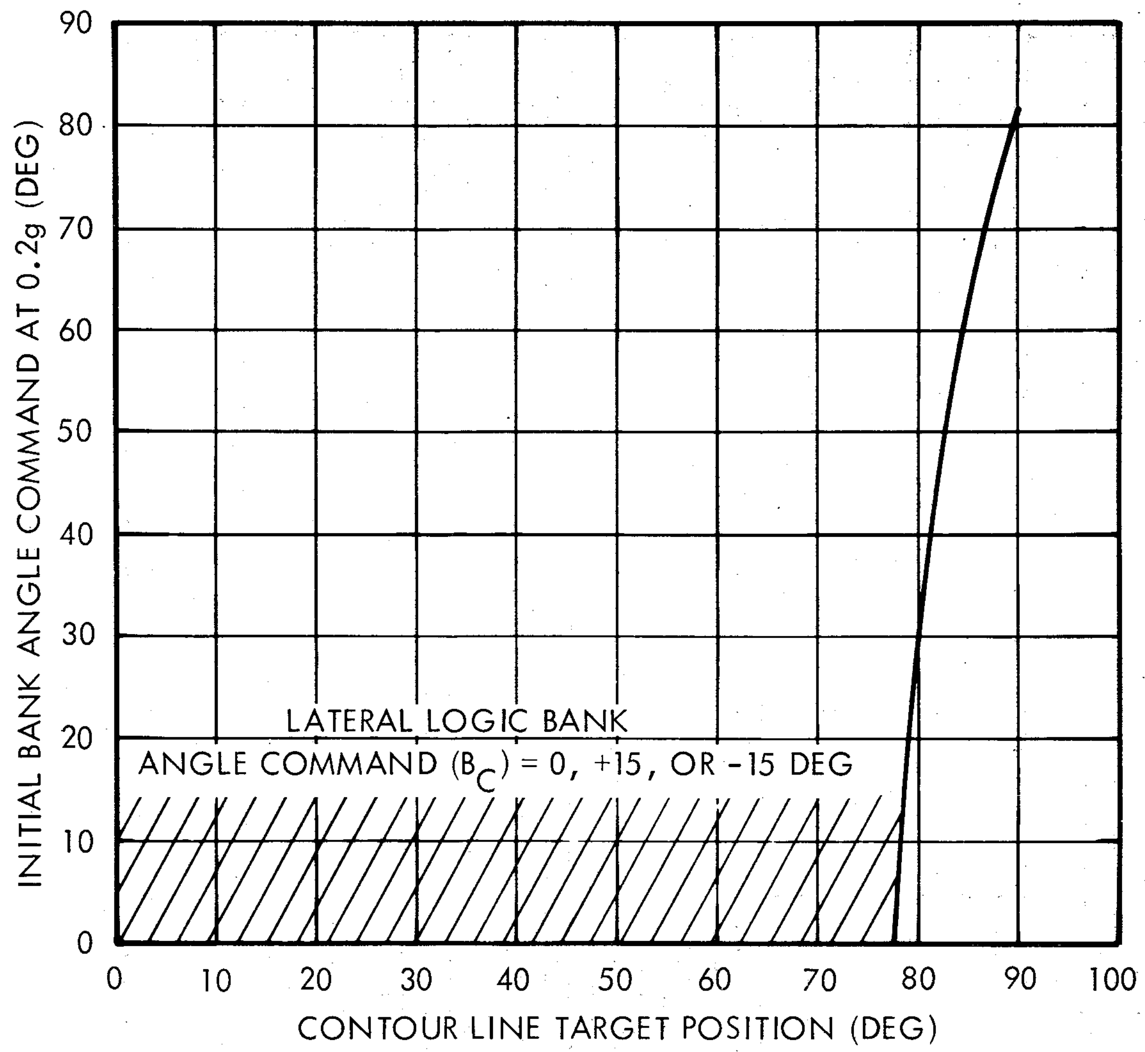


Figure 1. Initial Bank Angle Command at 0.2 g as a Function of Contour Line Target Position

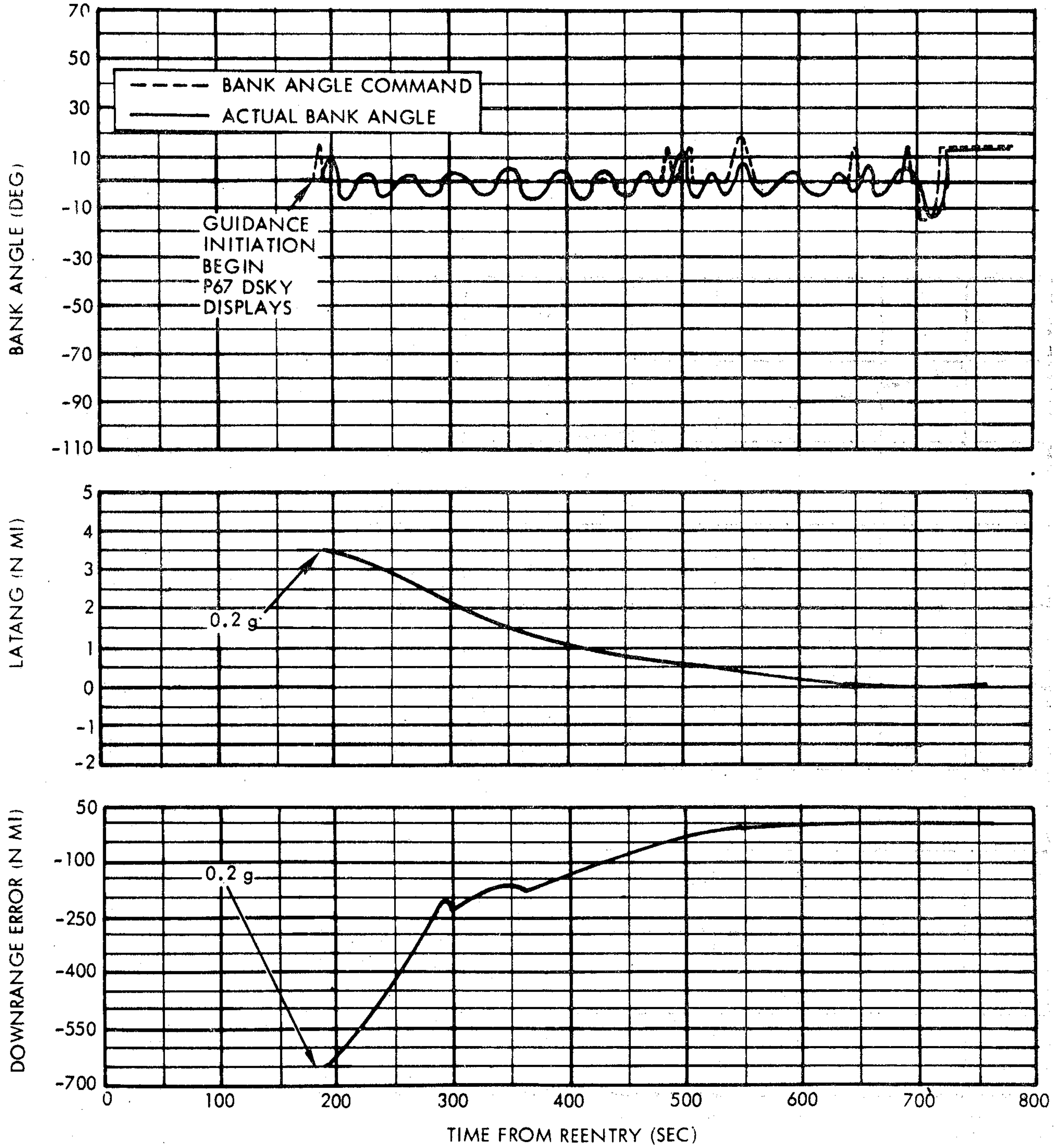


Figure 2. Final Phase (P67) Display History for Full-Lift Target

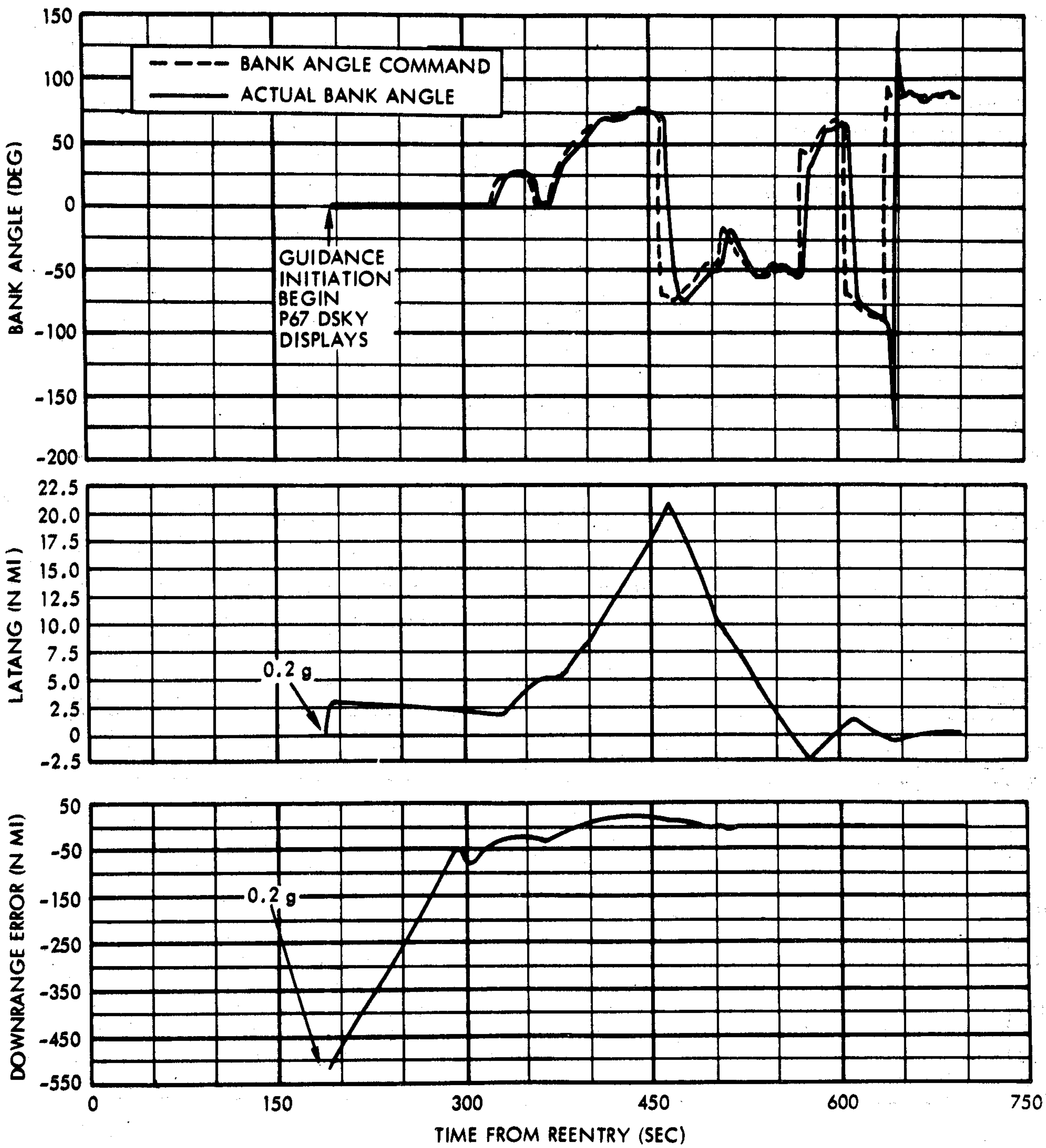


Figure 3. Final Phase (P67) Display History for 30-Degree Centerline Target

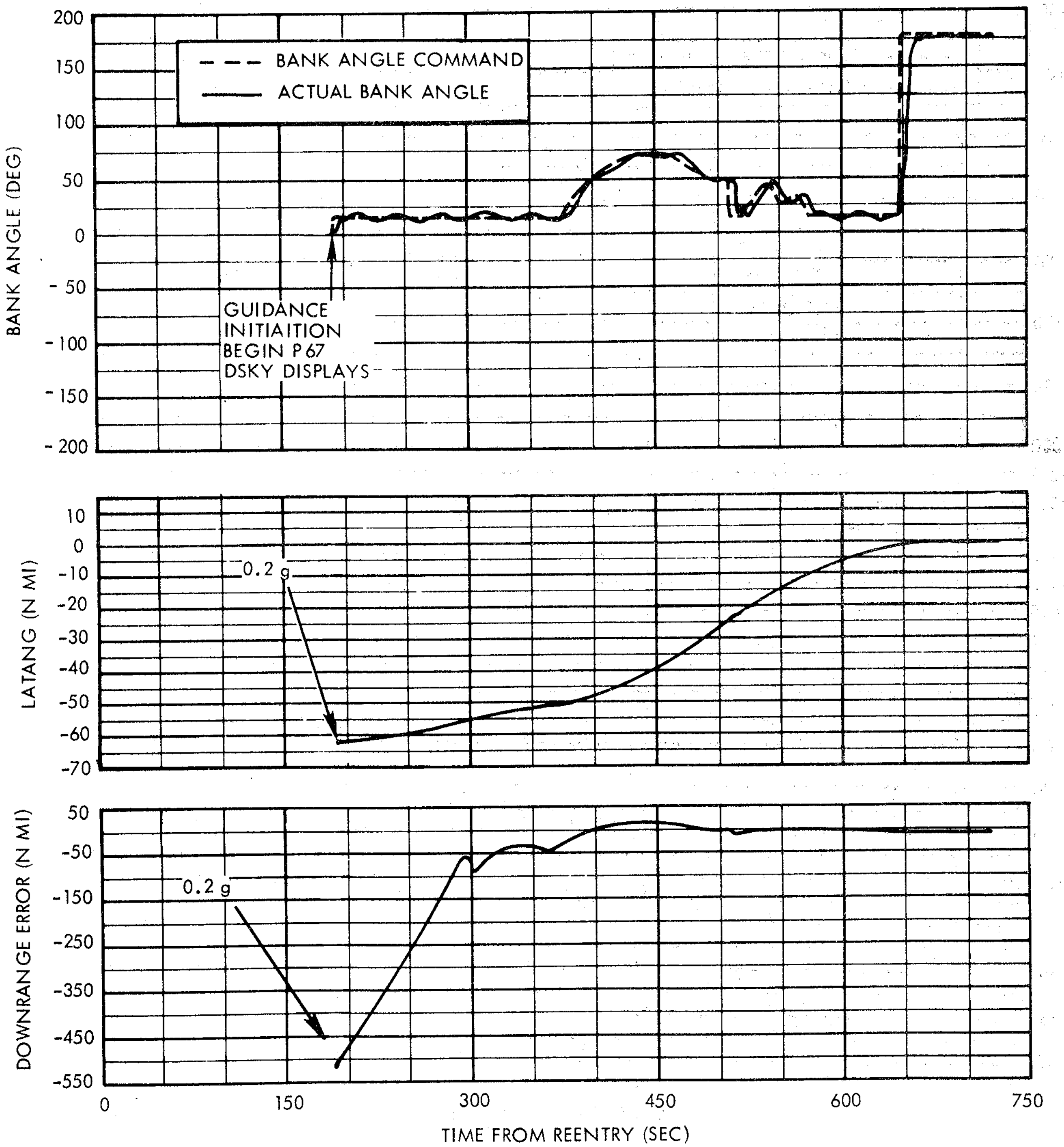


Figure 4. Final Phase (P67) Display History for Roll Right 30-Degree Target

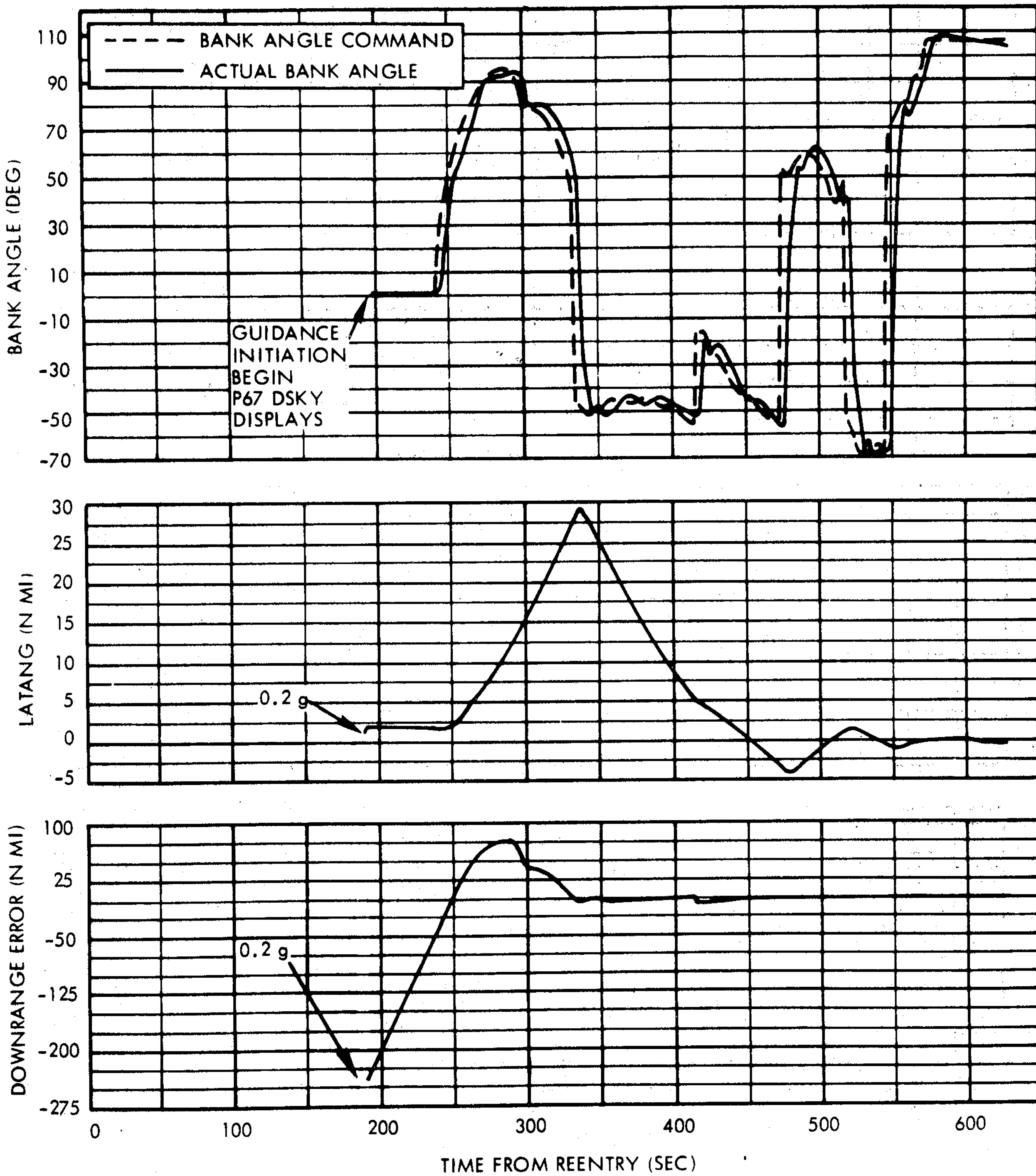


Figure 5. Final Phase (P67) Display History for 55-Degree Centerline Target

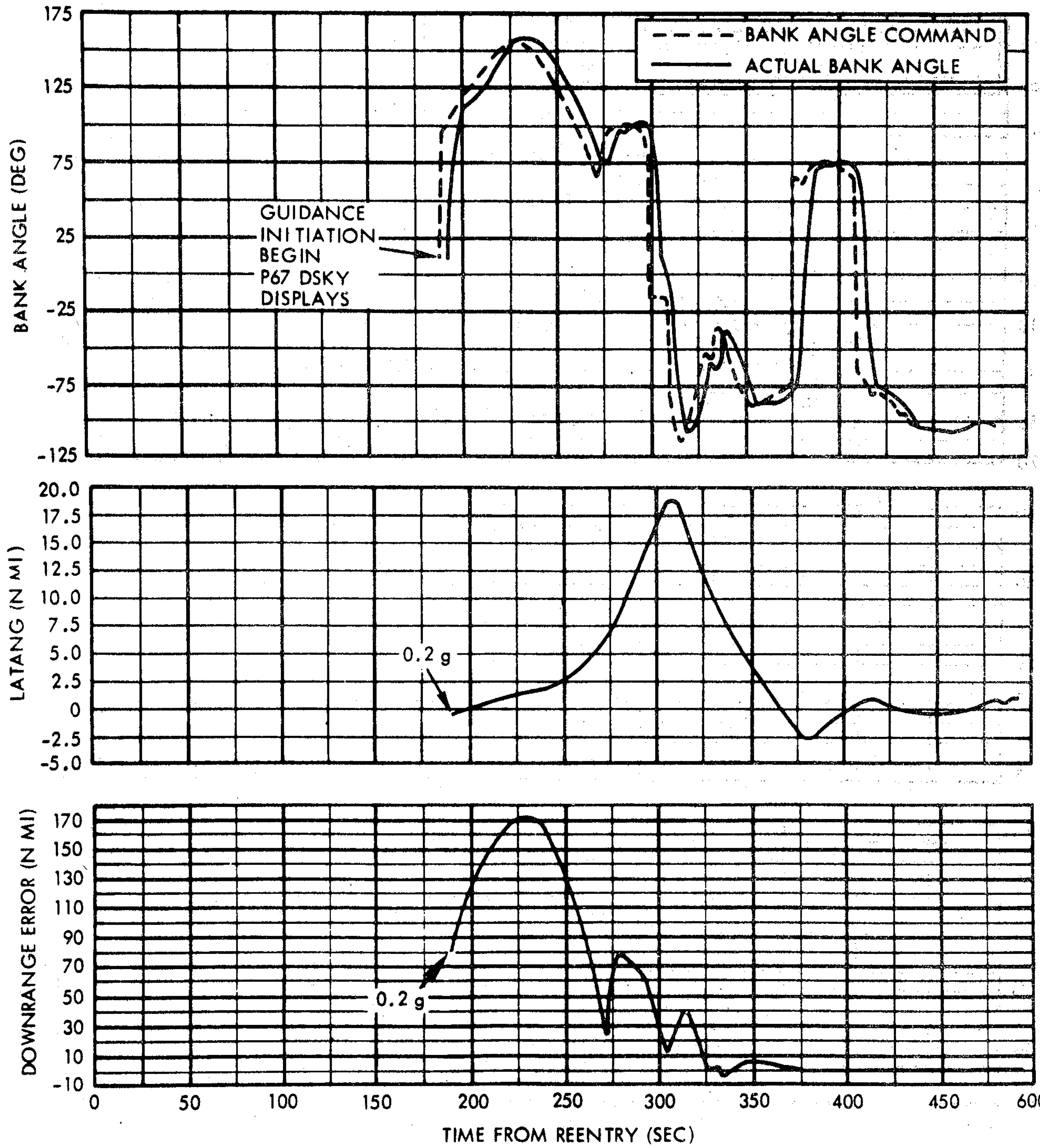


Figure 6. Final Phase (P67) Display History for 90-Degree Centerline Target

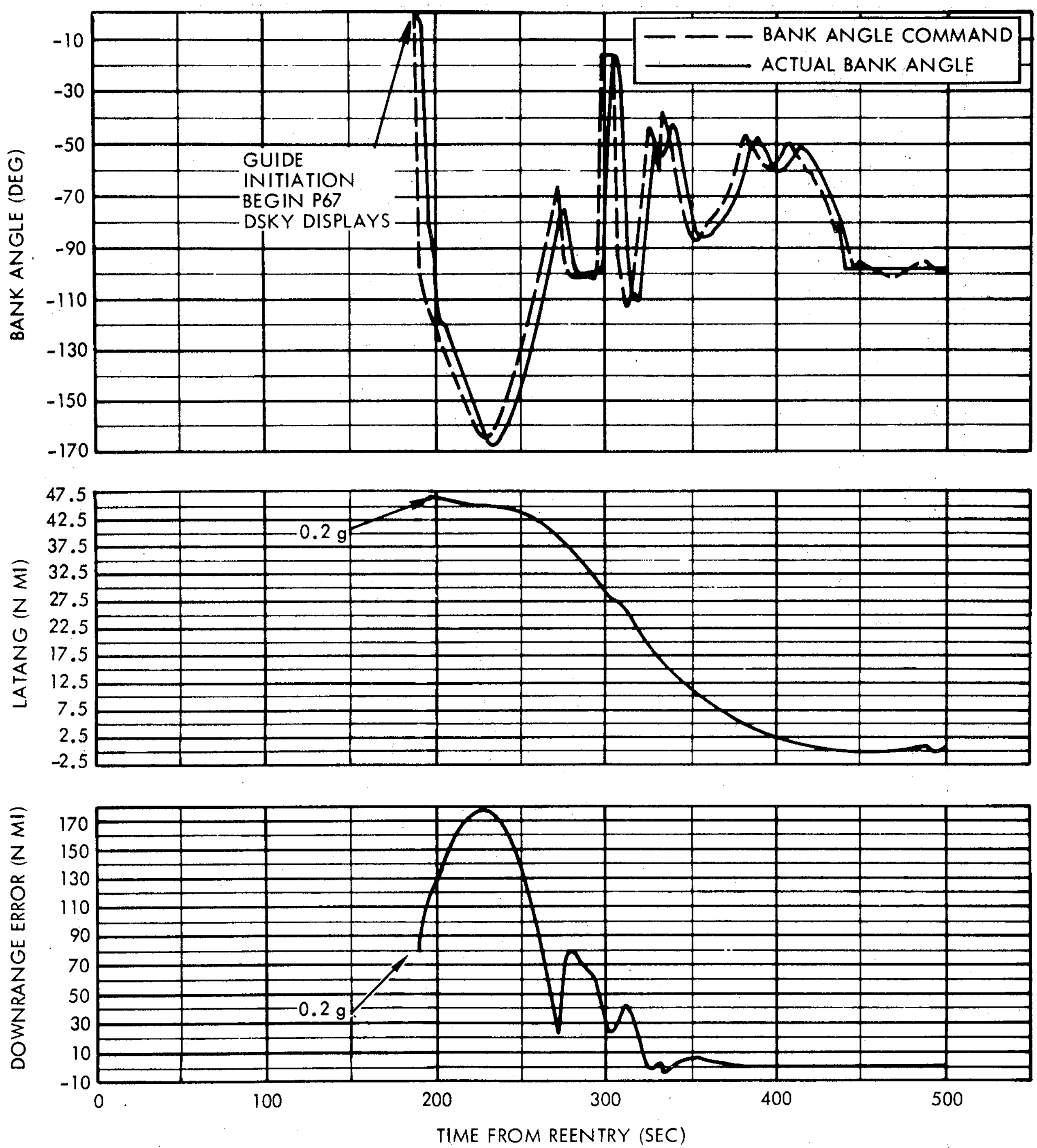


Figure 7. Final Phase (P67) Display History for Roll Left 90-Degree Target

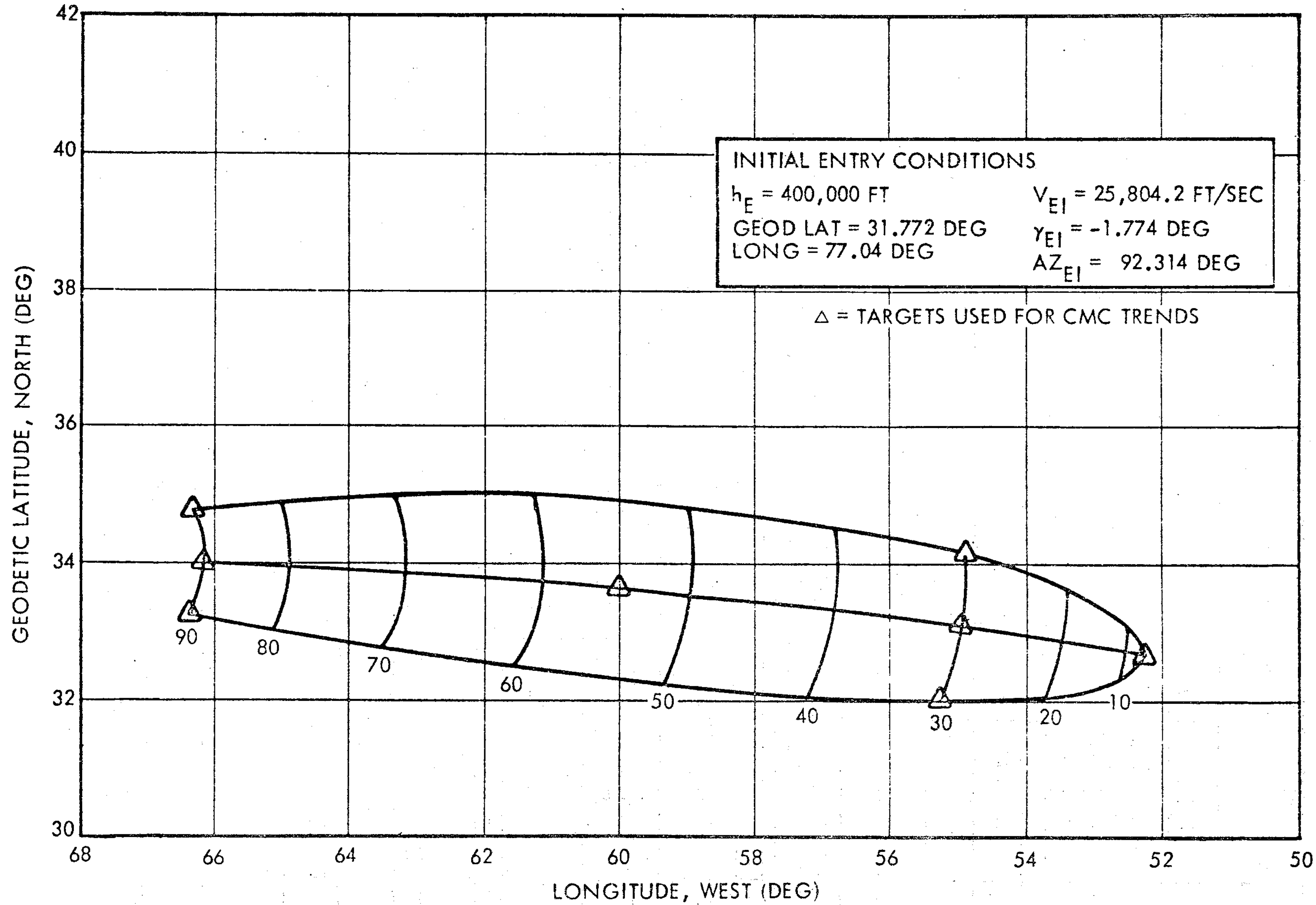


Figure 8. Open Loop Maneuver Footprint

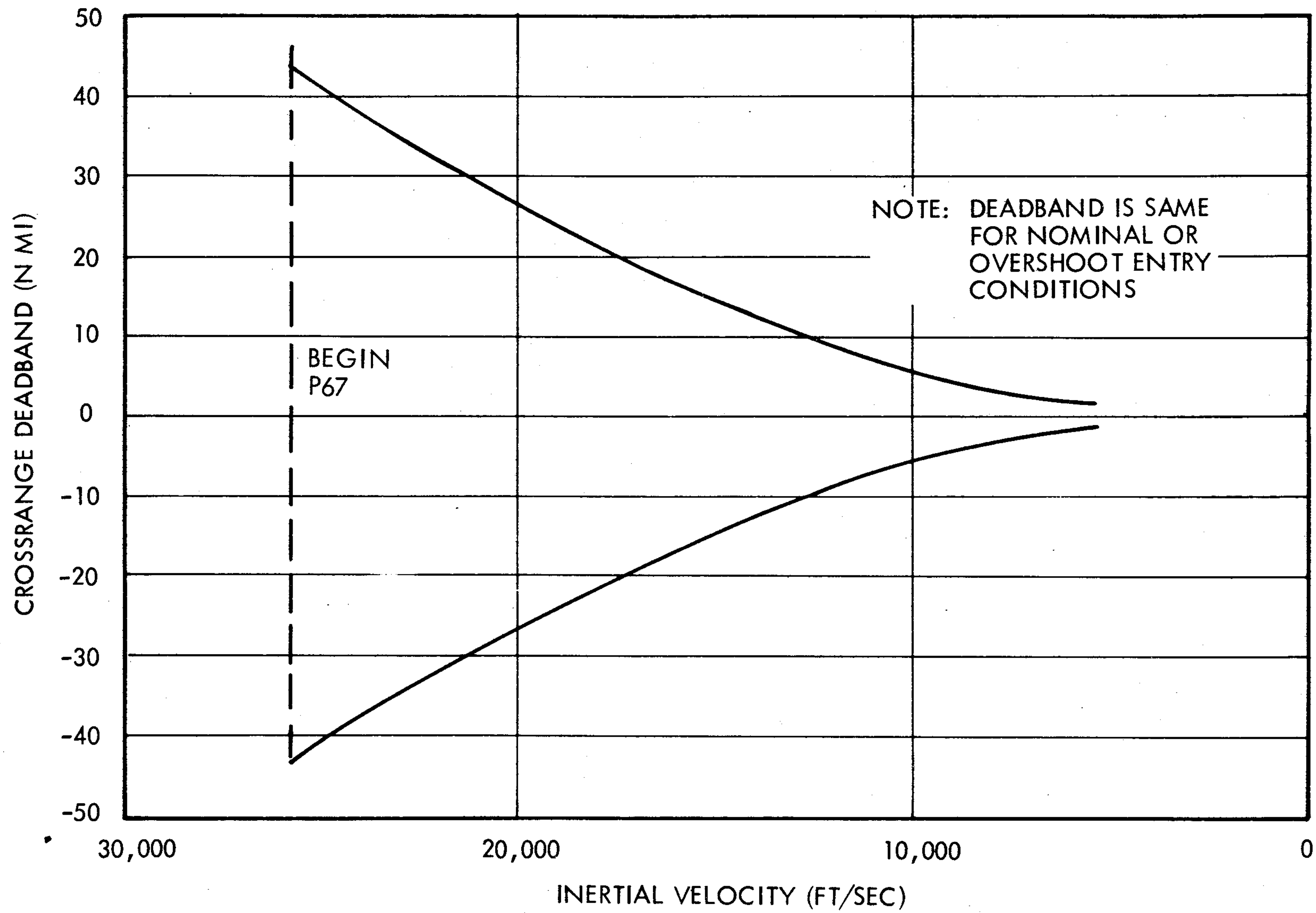


Figure 9. Crossrange Deadband as a Function of Inertial Velocity for 55-Degree Centerline Target

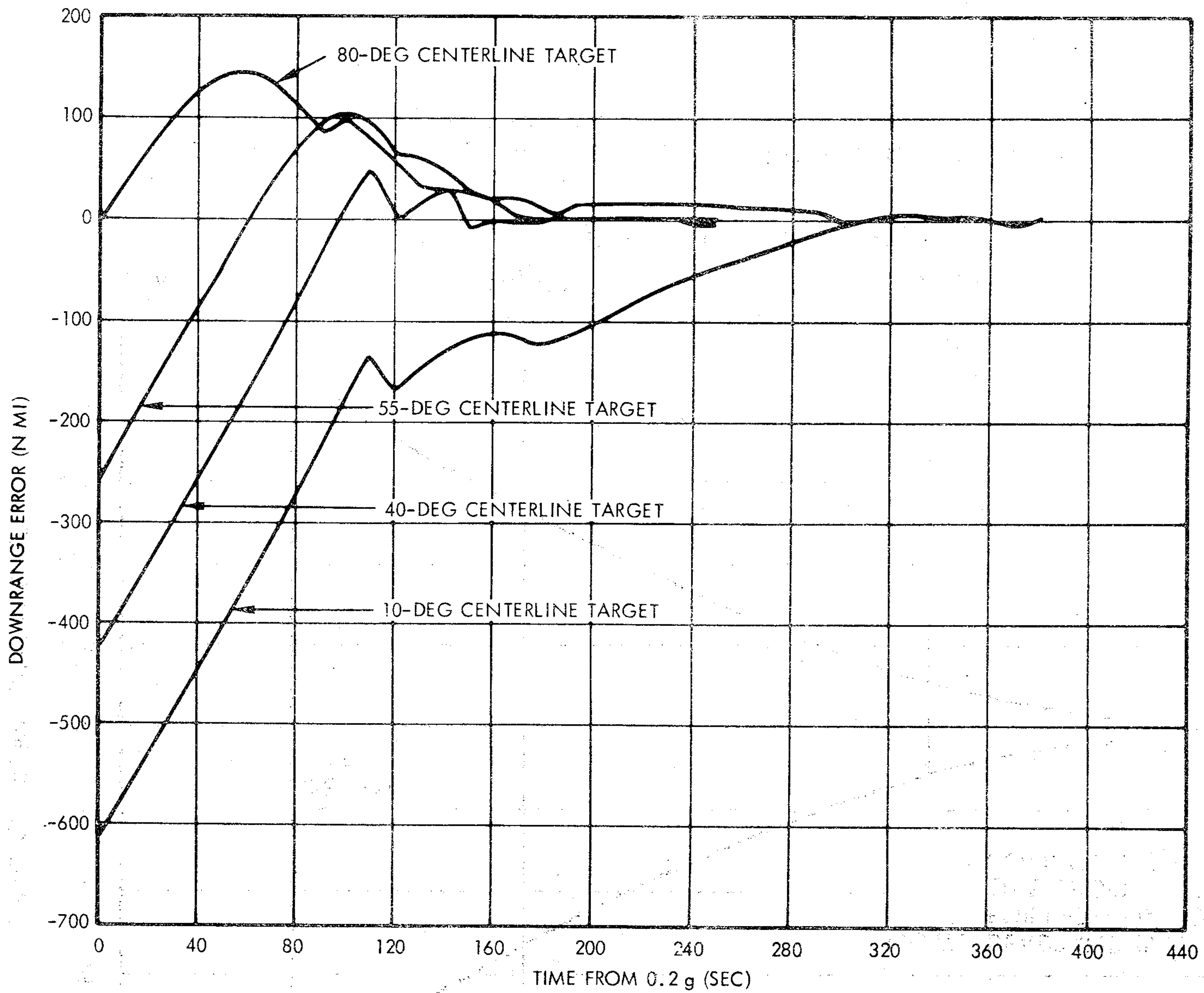


Figure 10. DRE as a Function of Time and Target Location

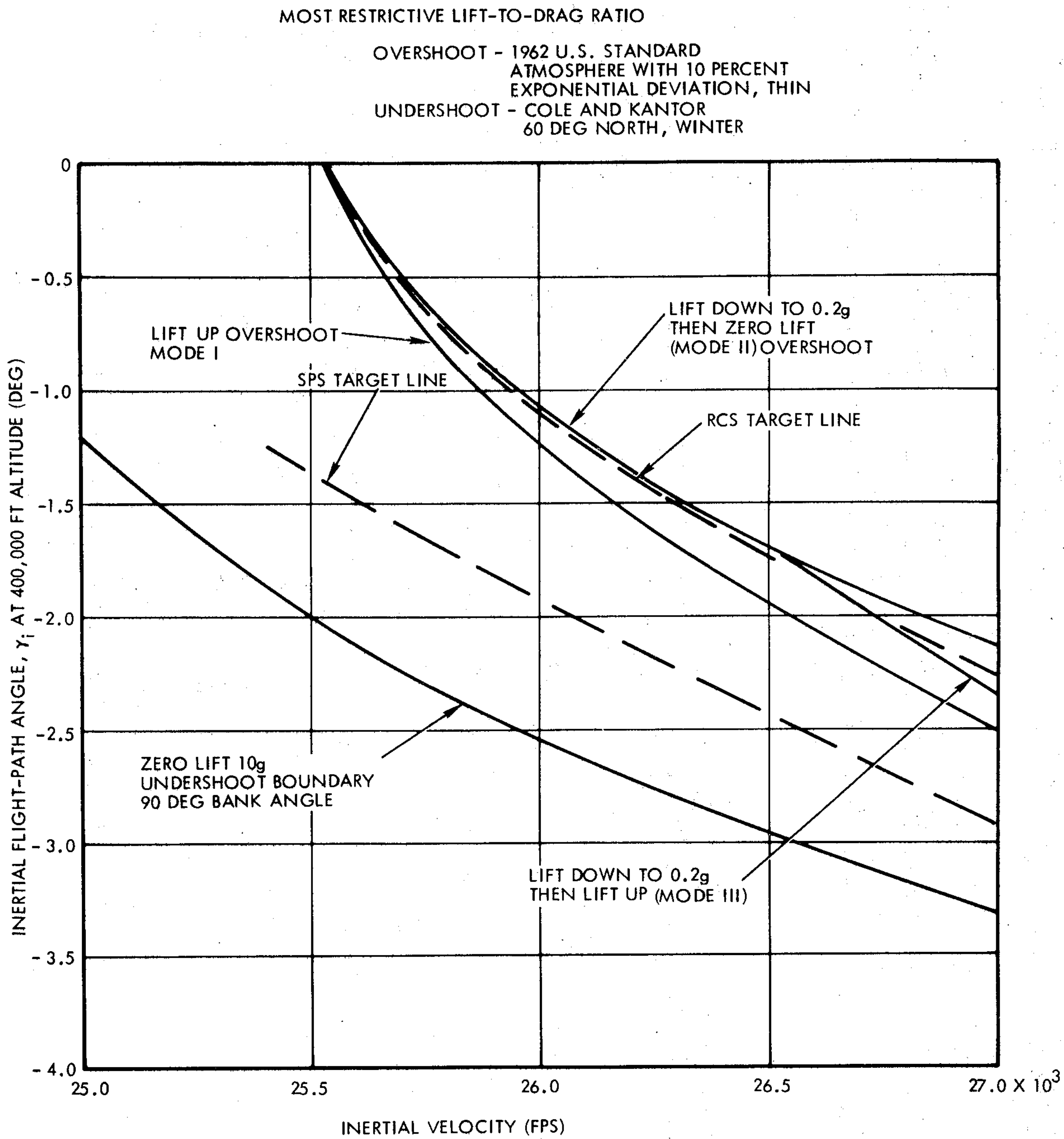
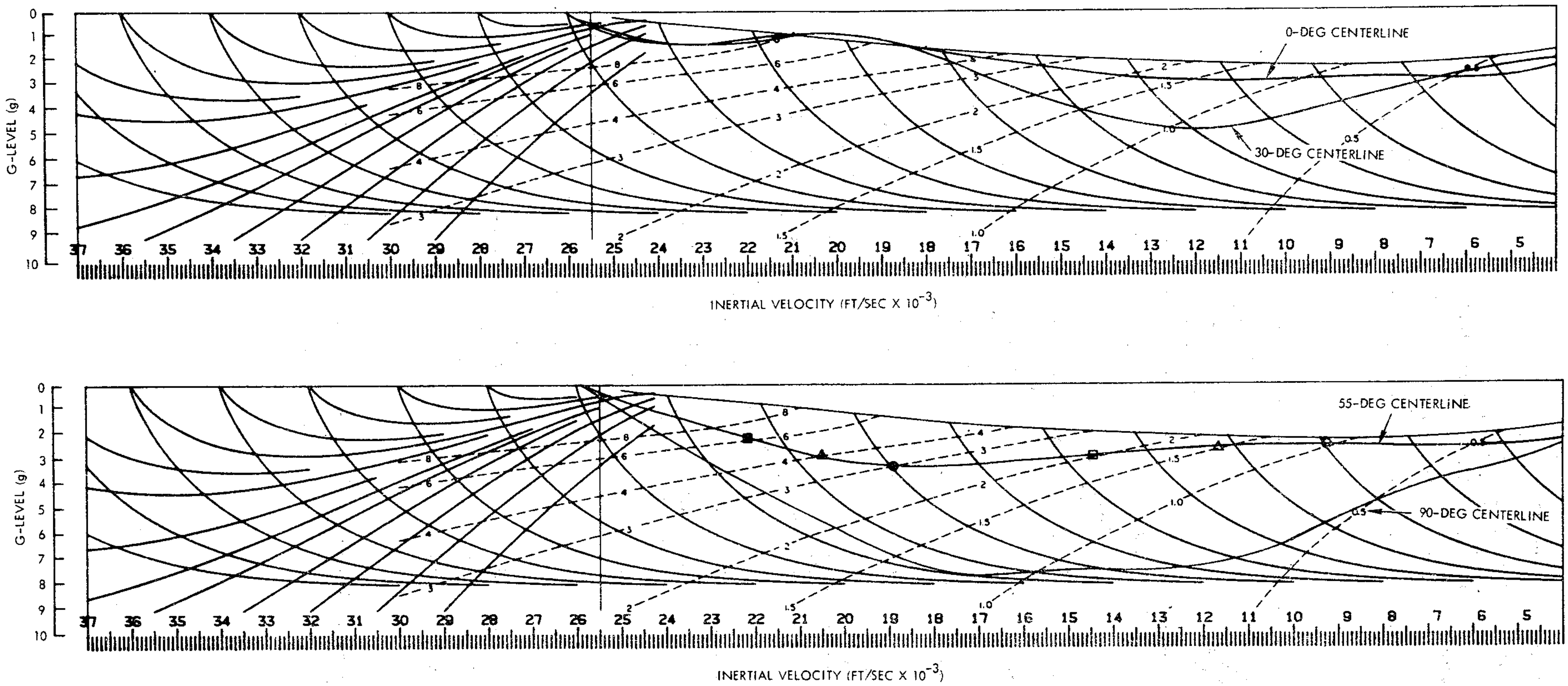


Figure 11. Near-Earth Orbital Entry Corridor



SYMBOL	MANEUVER CAPABILITY 55-DEG CENTERLINE (N MI) RANGE COUNTER	RANGE POTENTIAL	FULL-LIFT	ZERO-LIFT	MANEUVER CAPABILITY	PERCENTAGE OF FOOTPRINT
■	451	600	753	430	323	45
▲	363	400	501	241	260	36
●	295	300	380	171	209	29
□	180	200	231	137	94	13
△	129	150	166	114	42	6
○	91	100	110	83	27	4

Figure 12. Typical EMS Velocity - G Level Traces for G&N Centerline Targets

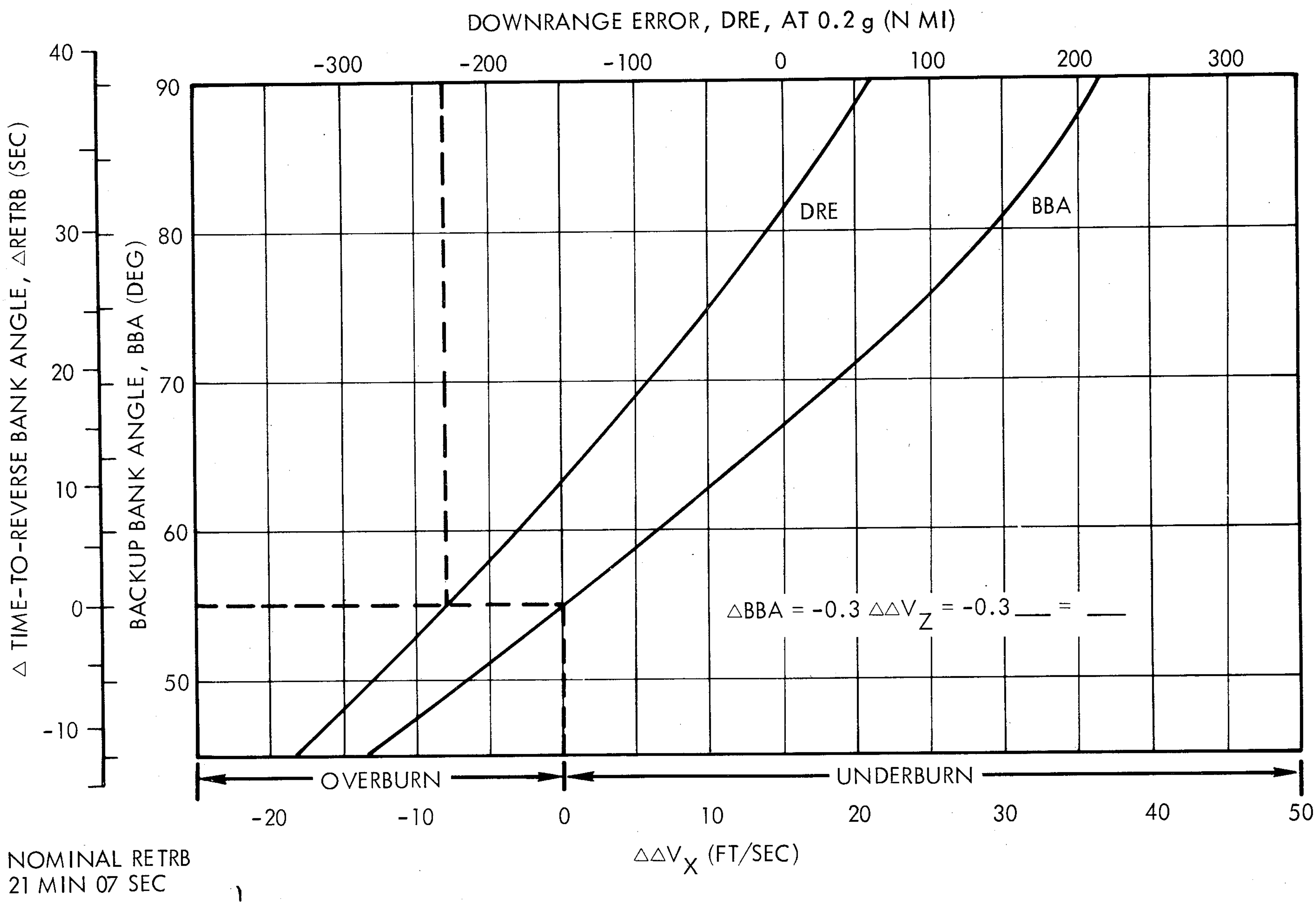


Figure 13. Recommended Guidance Update Onboard Backup Chart

REFERENCES

1. Reentry Monitoring and Backup Control Procedures for Mission D/CSM-104/LM-3. MSC IN 69-FM-13, January 22, 1969.

2. Reentry Monitoring and Backup Control Procedures for Near Earth Orbital Missions. MSC IN 68-FM-178, July 24, 1968.

3. Apollo Mission Techniques Earth Parking Orbit Retrofire and Entry Procedures (Missions C Prime, D, F, and G). MSC IN S-PA-8M-035, December 16, 1968.

4. Apollo Entry Summary Document Mission "D" (AS-504, CSM-104). MSC IN MSC-CF-P-68-29, December 16, 1968.